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CLINICAL COMMENTARY

PATIENT-SPECIFIC AND SURGERY-SPECIFIC FACTORS THAT AFFECT RETURN TO SPORT AFTER ACL RECONSTRUCTION

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ABSTRACT

Context: Anterior cruciate ligament (ACL) reconstruction is frequently performed to allow individuals to return to their pre-injury levels of sports participation, however, return to pre-injury level of sport is poor and re-injury rates are unacceptably high. Re-injury is likely associated with the timeframe and guidelines for return to sport (RTS). It is imperative for clinicians to recognize risk factors for re-injury and to ensure that modifiable risk factors are addressed prior to RTS. The purpose of this commentary is to summarize the current literature on the outcomes following return to sport after ACL reconstruction and to outline the biologic and patient-specific factors that should be considered when counseling an athlete on their progression through rehabilitation.

Evidence Acquisition: A comprehensive literature search was performed to identify RTS criteria and RTS rates after ACL reconstruction with consideration paid to graft healing, anatomic reconstruction, and risk factors for re-injury and revision. Results were screened for relevant original research articles and review articles, from which results were summarized.

Study Design: Clinical Review of the Literature

Results: Variable RTS rates are presented in the literature due to variable definitions of RTS ranging from a high threshold (return to competition) to low threshold (physician clearance for return to play). Re-injury and contralateral injury rates are greater than the risk for primary ACL injury, which may be related to insufficient RTS guidelines based on time from surgery, which do not allow for proper healing or resolution of post-operative impairments and elimination of risk factors associated with both primary and secondary ACL injuries.

Conclusions: RTS rates to pre-injury level of activity after ACLR are poor and the risk for graft injury or contralateral injury requiring an additional surgery is substantial. Resolving impairments while eliminating movement patterns associated with injury and allowing sufficient time for graft healing likely gives the athlete the best chance to RTS without further injury. Additional research is needed to identify objective imaging and functional testing criteria to improve clinical decision making for RTS after ACLR.

Level of Evidence: Level 5

Key Words: Anterior cruciate ligament, reconstruction, return to sport, rehabilitation, injury prevention

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INTRODUCTION

Return to sport participation after anterior cruciate ligament (ACL) reconstruction (ACLR) is an important measure in determining successful outcomes[1] and is an expectation of highly active individuals. The decision to clear a patient to progress rehabilitation to include demanding activities, such as cutting and plyometrics, and eventually return to sport must balance the wishes and desires of the patient with the current and future health of the knee joint. Conventional clinical advice is for athletes to return pre-injury sports participation between four and six months post-operatively,[2,3] however, time-based recommendations are based in theory and often do not accurately reflect patient capabilities. In a recent systematic review, 158 studies out of 264 (60%) utilized time after surgery as a criteria to return to sport. Of those 158, 84 (53%) determined that six months was the earliest that patients were allowed to return to sport. Only 35 studies (13%) used objective criteria to determine RTS readiness.[4] As this literature review shows, time after surgery is the most common criteria used to determine readiness to return to sport. At present, no set of criterion based measures have been adequately studied to determine whether or not they are appropriate for ensuring successful return to sport with the smallest possible chance of re-injury or contralateral knee injury.

The purpose of this commentary is to summarize the current literature on the outcomes following return to sport after ACL reconstruction and to outline the biologic and patient-specific factors that should be considered when counseling an athlete on their progression through rehabilitation. The factors addressed are not an all-inclusive list but the biologic factors are used to provide safe guidance based on time after surgery and the patient-specific factors are modifiable ones that guide the regular evaluation of motor control through the rehabilitation process.

DEFINING RETURN TO SPORT

When discussing return to sport after ACLR, a clear definition is needed due to the many contextual factors that surround sport. Return to sport[5] has been operationally defined as participation in regular season competition (or pre-season competition)[6,7] or physician clearance for return to training and match play.[8] Feller and Webster advocate clarity when discussing pre-injury sport and pre-operative sport, as pre-operative sport participation can be influenced in chronic ACL deficiency; and for distinguishing between training and competition, with respect to the level of competition and competency of participation.[5]

Careful attention should be paid to the reasons that individuals do not return to pre-injury participation with long term follow-up, as lifestyle changes and fear of re-injury may prevent return to pre-injury status as opposed to inadequate knee joint structure and function.[5,9,10] The authors advocate for classifying successful return to sport status to be defined based on returning to the same type, intensity and frequency of activity as at the time of injury, and having at least the same Marx Activity Rating Scale scores.[11] Cameron et al reported that men with a history of knee injuries have a mean Marx score of 12.58 and men with no history of knee injuries have a mean score of 12.17. Women with a history of knee injuries have a mean Marx score of 12.39 and women with no history of knee injuries have a mean score of 10.94.[12] Comparing the frequency of running, cutting, twisting, and jumping and the above referenced Marx scores before injury and after surgery reduces the chance of incorrectly identifying individuals as having successfully returned to sport by decreasing the demands of the sport itself (i.e. the individual may have returned to playing soccer, but does not perform the demands of sport as often). Furthermore, reasons for decline in sports activity and participation after surgery should be thoroughly documented, and the individual's satisfaction with their activity level should be considered. This definition of return to sport provides a more comprehensive representation of activity level than does the Tegner Activity Scale, which has noted flaws in the measurement of activity level towards the higher end of the scale.[8]

CURRENT RETURN TO SPORT LITERATURE

In a study that followed 503 individuals for 12 months after ACLR, only one-third of individuals had attempted full competition, one-third were in training or modified competition, and one-third had not attempted training or return to sport.[13] Younger athletes, males, and those athletes who participated in seasonal team sports were more likely to attempt return to sport by one year after ACL reconstruction.[13] In further follow-up at an average of 3.5 years after ACLR, return to sport rates improved to 82% for individuals attempting to return to some form of sports, however, only two-thirds of individuals returned to their pre-injury level of sport participation, and less than half returned to competitive sports.[9] The rate of return to pre-injury sports is lower (61.9%) for participants in cutting and pivoting sports (Level 1) than for individuals who participated in sports (77.8%) with less challenging lateral movements (Level 2).[14]

Return to sport rates have been investigated for specific Level 1 sports, defined as sports which challenge knee joint stability in the transverse plane involving jumping, cutting, and pivoting such as football, soccer, or basketball. A wide range of success rates for specific sports exists in the literature: 63% - 69% for American football (high school, college, NFL),[6,10] 78% in the National Basketball Association[5], and 72% - 89% in soccer.[7,15] Age is a significant factor in whether an athlete will return to sport. More than 70% of individuals under the age of 25 were able to return to either strenuous or very strenuous sports (cutting, pivoting, and/or lateral movements), but only between 43% and 57% were able to resume pre-injury activity levels.[16] The risk of subsequent injury to either knee was 17% for patients younger than 18 years of age, 7% for patients 18 to 25 years of age, and 4% for patients older than 25 years of age.[17] Regardless of the actual short-term rate of return to sport, participation declines with longer duration post-operative follow-up, which likely follows the natural history of an individual's athletic career.[15,18]

BIOLOGICAL AND SURGICAL CONSIDERATIONS FOR RETURN TO SPORT DECISIONS

The selection of either autograft or allograft tissue for ACLR is usually based on patient and surgeon preference, patient age, activity level, physical requirements, timeline for return to play, as well as comorbidities and concomitant injuries.[19] When making the return to sports decision, a primary factor to consider is prevention of recurrent injury by ensuring that the graft has healed appropriately and is capable of withstanding the demands placed upon it. Following ACL reconstruction, the graft undergoes a process of "ligamentization" whereby the tissue transitions from its natural state to a structure that approximates the native ACL (but does not achieve the exact ultra-structure of the native ACL), thus being able to better withstand the forces that the native ligament experiences.[20,21,22,23,24] Healing progresses from an early phase, to a remodeling phase and finally a maturation phase, each of which have been extensively studied in animal models, and supported by studies that utilize human graft biopsies. At the time of graft implantation, the tissue is avascular, however it quickly becomes enveloped in synovium and vascularity increases to the point of hypervascularity when compared to a native ACL. At the time of complete maturation, the vascular supply decreases until the normal vascular pattern of the ACL is restored.[25] Immediately after implantation, the graft microstructure progresses from uniformly oriented collagen fibers consistent with the harvested tissue, to a mature state with the graft containing collagen fibers capable of resisting the forces experienced by the native ACL. The biomechanical strength of a graft varies as it undergoes maturation and remodeling, making graft maturity an important aspect in determining when an athlete should return to sport, however the ability to accurately assess the state of graft healing and maturation is currently lacking. This further demonstrates the need for a criterion based program in conjunction with time-based suggestions for timeframes for return after surgery.

The proposed rehabilitation protocol (Appendix 1) is an example of a criterion-based progression that takes time after surgery into account in order to allow for graft healing and maturation. The protocol includes certain time criteria to advance between phases per the surgeon's preference to work in conjunction with criterion-based progression. In the early phases, exercises are specifically selected to meet the early ROM goals, surgeon specific criteria for discharging the brace and crutches, and achieving normal gait. Exercises are then specifically chosen to meet the strength and motor control demands of running, and progressing through functional training to prepare to return to sport.

Human Graft Biopsy Studies

Although the graft itself is not vascularized at the time of reconstruction, signs of vascularity are present within the graft as early as three weeks after surgery. [23] The early stage may resolve as early as three months post-operatively, although the transition to the remodeling phase may occur as late as 12 months.[23,24] The graft then enters the maturation phase between nine and 18 months following surgery.[20,24] Although it appears the graft undergoes "ligamentization", biopsies have only been obtained from a single sample during the post-operative period.

Graft strength is lowest during the remodeling phase, between two and six weeks, and subsequently improves to final state during the maturation stage. As a result, the graft appears to be most tenuous during the remodeling phase, and measures should be taken to avoid returning athletes to sport until the vascularity of the graft has decreased inferring the end of the remodeling phase of healing.

Measuring Graft Healing In-vivo

While the invasive nature of biopsy does not allow serial investigation of graft healing, noninvasive magnetic resonance imaging (MRI) can monitor the progress of healing and maturation of the graft. MRI has been investigated to monitor changes in graft vascularity as a correlate to graft incorporation using signal intensity as a marker of vascularity.[26,27,28] The Signal to Noise Quotient (SNQ) standardizes signal intensity of a graft. Serial examinations of individuals that underwent ACL reconstruction with allograft and autograft demonstrated an increase in SNQ on proton density weighted images after implantation followed by a decrease, with signs of graft maturity earlier with autograft (two to six months) compared to allograft reconstructions (nine to 12 months).[28] Ntoulia et al specifically examined the maturation of bone-patellar tendon-bone autograft in humans and found vascularity decreased to a state similar to the native ACL between six and 12 months post-operatively.[30]

MRI can be used to show the changes in the biomechanical qualities of a graft. In a study utilizing Achilles tendon autograft in a sheep model, as the graft matured, its SNQ normalized.[30] Fleming et al. examined a goat model with patellar tendon autograft for ACL reconstruction and found that as graft volume increased in a goat model, so did the ultimate failure of the graft.[26] The structural properties (maximum load, yield load, linear stiffness) of the repaired ACL and the ACL graft after reconstruction can be predicted by T2* volume and signal intensity values in a porcine model.[31,32] The various emerging technologies in MR imaging need to be further validated before becoming commonplace in clinical practice, but given the preliminary findings, especially in individuals where early return to sport is being considered, advanced imaging such as MRI may be useful in contributing to making the decision of whether that athlete should be released to full participation with regard to graft healing.

Anatomic Reconstruction and Implications for Return to Sport

Recently, focus has shifted on recreating the anatomy of the native ACL and away from non-anatomic positioning of the graft that is dictated by the transtibial approach to create the femoral tunnel. By modifying the surgical technique, surgeons hope to restore native knee kinematics and oppose translational and rotational forces better than the traditional transtibial drilling technique.[33,34] Double-bundle anatomic ACLR controls anteroposterior and rotational laxity[35] and replicates the native force distribution better than non-anatomic ACLR, which disperses more forces across the surrounding structures such as the articular cartilage and secondary stabilizers.[36] Anatomic placement of the graft results in increased in situ loading of the graft when compared to non-anatomic graft placement.[36] By reproducing native knee kinematics, fewer forces are transmitted across secondary stabilizers with less shear forces across the articular cartilage, potentially staving off the development and progression of post-traumatic knee osteoarthritis (OA). The increased forces seen by an anatomically placed graft may increase the risk of re-injury; therefore care must be taken to allow the graft to heal and become biomechanically strong before return to sport after anatomic ACLR. For the elite athlete who demands the highest level of stability and function, it is the opinion of the authors that it may be beneficial to receive an anatomic reconstruction, which will more closely recreate pre-injury function of their knee, although the risk of re-injury may be greater than when the graft is placed non-anatomically.

ESTABLISHED RISK FACTORS FOR RE-INJURY AND IMPLICATIONS FOR LATE PHASE REHABILITATION

In addition to poorer than expected rates of return to pre-injury sport, re-injury or an injury to the contra-lateral knee are common after ACLR.[37] The risk for re-injury to the reconstructed knee requiring revision surgery ranges from 2.6% to 17% five years following ACLR.[38,17,39] Contra-lateral knee injury within five years occurs in up to 11.8% (8.2%-16.0%) of individuals.[39,40] Within the first twelve months after ACLR, the incidence of a second ACL injury is 15 times greater than that of healthy controls experiencing a primary ACL tear.[41]

Time after ACLR is the most frequently cited criteria for allowing individuals to return to sport,[4] which may play a contributory role in ACL injury or rupture. Surgeons may clear a patient to return to sport after a certain timeframe, regardless of functional capacity. Individuals may return to sport between two and 24 months post-operatively, with the average being about seven months.[9] As discussed previously, return to sports within the first year after injury may not be advisable, as re-injury rates are highest during this time.[42] While the six-month time frame may be adequate to ensure that the graft is progressing through the remodeling phase and into the maturation phase, functional performance measures are not related to time from surgery.[43] Therefore, clearance to begin a new activity and progress through the rehabilitation process is dependent upon both functional capacity and time after surgery, and not just a time after surgery requirement. Because of the high rate of re-injury in the first year after ACLR and the time required for the graft to remodel to a somewhat steady state, the program developed at the University of Pittsburgh Medical Center (UMPC) Center for Sports Medicine (Appendix 1) suggests that individuals return to sport around eight to twelve months after ACLR, pending achievement of clinical milestones. The proposed program is based on the best available evidence and is currently being tested in order to determine its effectiveness on both performance improvement and injury risk reduction.

Aberrant movement patterns involving femoral internal rotation and adduction, knee abduction, tibial external rotation and ankle eversion (operationally defined and clinically referred to as "dynamic valgus") with low knee flexion excursions and large vertical ground reaction forces increase the risk for injury in both the ACLR and healthy populations.[44,46,47] However, at least one large study has demonstrated that landing mechanics are not associated with risk for ACL injury.[48] Dynamic valgus observed during landing from jumps and cutting maneuvers is associated with greater ACL injury risk,[49,50] and may persist after reconstruction.[51,52,53,54] Poor postural stability, weakness of the hip musculature, and dynamic valgus landing mechanics increase the risk of sustaining a second ACL injury.[47,55] Poor neuromuscular control can lead to a lateral trunk lean increasing the knee abduction moment[46,49] and strain placed on the ACL, also increasing the risk of injury. [46,47,49]

Normalizing mechanics with specific interventions to restore symmetrical and normal movement patterns during rehabilitation following ACLR should be prioritized during the rehabilitation exercise progression.[56] Movement retraining should begin early in rehabilitation during single limb balance tasks, step-down tasks and single leg squats. Movement symmetry and quality with jump-landing and cutting strategies should be the emphasis during the later phases of rehabilitation. During the phase of rehabilitation that allows for plyometrics, education regarding appropriate jumping and landing techniques can improve landing patterns with the use of verbal cues, demonstration of proper and improper landing patterns, increasing landing time, increasing knee flexion angles upon landing, and decreasing vertical ground reaction forces in female high school female athletes.[57] Decreased hip muscle activation has been linked to higher GRF in female athletes who suffered ACL injury[44] and dynamic valgus can be controlled with appropriate hip abductor muscle activation and recruitment.[58] Hip abductor and external rotator strengthening in order to facilitate proper eccentric control during sport specific activities should be included in the rehabilitation program, although activity and sport-specific training to control position of the knee joint is also necessary because a crossover from isolated strengthening activities to sport specific activities may not occur without task-specific training.[59] Time from injury and neuromuscular control are the only risk factors that have been identified which are modifiable in the return to sport process. Normal mechanics should be stressed during the entire rehabilitation process, as it has been shown that females two years after ACL reconstruction demonstrate limb asymmetries during landing and takeoff phases for the drop vertical jump.[45] Hewett et al. found that excessive knee abduction moments during landing from a drop vertical jump predicted ACL injuries with 73% specificity and 78% sensitivity.[46] For this reason, one of the criteria to advance to the phase that includes cutting in the attached protocol is the demonstration of full motor control and normal mechanics with jumping, i.e. the assessment of mastery.

Individuals must demonstrate mastery of the rehabilitation goals of the current phase before progressing to the next phase. Mastery is typically assessed through observation of the highest level of performance allowed in the progression. Failure to master the tasks of an individual phase is mediated with focused practice and instruction in proper technique. The inclusion of activity mastery as a prerequisite for advancement to the next phase ensures that individuals take time to practice each skill and incorporate good movement patterns during dynamic tasks even if their strength and neuromuscular control would allow them to progress in multiple phases

Females are four to six times more likely to sustain major knee injuries than men.[60] Female athletes are at high risk for sustaining a primary ACL injury, and the risk of re-injury after ACLR may be four times as high for the ipsilateral knee and six times as high for the contralateral knee in the first year of participation after reconstruction when compared to male athletes.[17,41] The risk factors and rates of occurrence for a second injury after ACLR in young female athletes are consistent with those established for primary ACL injuries.[47,59] The effect of gender is likely due to females demonstrating greater dynamic valgus than males,[44] although Smith et al have shown that landing mechanics are not predictive of injury regardless of sex.[48] Female volleyball players demonstrated greater vertical ground reaction forces when performing spike and block landings,[62] although those differences were not seen in a controlled laboratory setting.[63] Again, this demonstrates the need for the assessment of task mastery in each phase and may delay a surgeon clearing a patient for early return to sport. Age plays a role in the risk for re-injury.[64] Individuals younger than 20 have twice the risk of a second injury compared to older individuals.[38,39] In high school sports, girls have a rate of 7.2 primary or secondary ACL injuries per 100,000 athletic exposures; boys have a 6.2 rate of primary or secondary ACL injuries per 100,000 athletic exposures.[65] The relationship between age and re-injury is further demonstrated when looking at the effect of typical milestones in an American population: school age populations (younger than 18) have a 13% to 17% incidence of secondary injury which decreases when reaching the typical collegiate and post-collegiate ages (18 to 25 years - 7% to 8% secondary injury) and further decreases in those older than 25 years.[17,39] The greater risk of re-injury in younger individuals is likely due to returning to sports within the first year after ACLR more often than older subjects.[9] This provides a greater exposure to potentially injurious situations in the six to 12 month time period when a majority of re-injuries occur.[42] Other non-modifiable risk factors have been cited, which include joint geometry, familial pre-disposition, and hormonal aspects.[37,66] The risk for re-injury can be mitigated in spite of some of these non-modifiable risk factors by not allowing athletes to return to sport until healing (as evidenced by normalization of graft vascularity) has occurred and functional performance on objective tests dictates that the individual has achieved symmetrical knee function and demonstrates the elimination of movement patterns that are associated with second injury.

CONSIDERATIONS FOR EARLY REHABILITATION

Before beginning the return to sport phase, basic knee impairments need to be resolved. Full flexion and extension range of motion equal to the contralateral limb needs to be achieved, with referral back to the physician for further assessment suggested if full symmetrical extension is not achieved by one month post-operatively. Referral to the physician may be considered to rule out operative complications, septic arthritis, and localized conditions including intra-articular lesions (cyclops lesions), hemarthrosis, or cyst development. Effusion is an outward sign of joint inflammation and should be resolved within the first few months after injury. The stroke test is a reliable test for detecting the presence and quantity of knee joint effusion and has been used clinically to determine tolerance to functional activities in response to increases in exercise intensity, (i.e. if joint effusion increases after the introduction of an activity, the knee is not ready to continue that activity).[67] Joint effusion may reflexively inhibit the quadriceps, limiting force production,[68,69] delaying recovery,[17] however the mere absence of a joint effusion is not sufficient to assume that full quadriceps activation is present.[70] Numerous criterion based protocols and reviews are available to guide appropriate early post-operative rehabilitation.[71,72] The recommendations throughout the rest of this manuscript assume full active and passive motion has been achieved; and that the individual demonstrates good quadriceps activation and can perform a straight leg without a lag.

THIGH MUSCLE STRENGTH SYMMETRY

Periods of disuse after injury and ACLR can result in quadriceps muscle strength asymmetry between the injured and uninjured limbs. Individuals with strength deficits of the involved limb perform worse on patient-reported outcome measures and performance-based functional tests.[73,74,75] These weaker individuals jog similarly to injured subjects with truncated knee motion,[76] and have a greater incidence of anterior knee pain and early onset development of osteoarthritis.[77] Quadriceps asymmetry of 20% or more is frequently seen in individuals six months after ACLR,[74] and the incidence may be as high as 24% of individuals one year after ACLR.[78]

The pre-return to sport time frame needs to incorporate aggressive quadriceps strengthening, including both non-weight bearing (NWB) and weight bearing (WB) exercises in order to assist the athlete in regaining full strength.[79] Non-weight bearing leg extension exercises are frequently avoided because they can place undue strain on the graft;[80,81,82] however, quadriceps contractions in the range from 90º to 50º of knee flexion do not exert an unsafe anterior translation force on the tibia, thus do not place excess strain on the graft and are appropriate and safe to use after ACL reconstruction.[79] Non-weight bearing exercises between 90 degrees and 60 degrees of knee flexion should be implemented immediately after ACLR to provide isolated resistance to the quadriceps. At four months post-ACLR as the graft remodeling phase peaks, the range of motion for NWB exercise can be progressed about five degrees per week to slowly increase the load experienced by the ACL. The amount of resistance selected should be based upon the presence of any patellofemoral pain. In weight bearing, , quadriceps strengthening exercises should be performed from 0 degrees to 45 degrees,[79] since the hamstrings are active in more extended ranges of the knee. At approximately three months post-op, the range of motion for closed chain exercises can be progressed gradually as the graft is expected to be transitioning to the maturation phase.

Neuromuscular electrical stimulation (NMES) can facilitate re-education of the quadriceps, particularly when quadriceps activation is inhibited due to pain, effusion, or muscle atrophy,[83] to help restore quadriceps strength. The use of high intensity NMES improves patient reported outcome scores, volitional activation of the quadriceps, and facilitates a greater proportion of individuals to meet criteria for progression to agility exercises.[84,85] Neuromuscular electrical stimulation can be completed with the knee joint in full extension to promote quadriceps activation during terminal knee extension and can be used immediately after surgery.[84] A transition to application of neuromuscular electrical stimulation with the knee positioned between 60 and 90° of flexion in the isometric mode on an isokinetic dynamometer can help to ensure a therapeutic dose of electrical stimulation when the intensity is set to ≥50% maximum voluntary isometric torque.[85]

Contraction of the hamstrings can assist in resisting anterior tibial translation and reducing strain and stress on the graft;[78] however, hamstring strength is not associated with functional outcomes.[86] Individuals undergoing ACLR with hamstring autografts may present with greater hamstring strength deficits[87,88] when compared to those who have had other grafts. These strength deficits may be greater when both the semitendinosus and gracilis are harvested, as compared to harvest of the semitendinosus only, especially at greater knee flexion angles.[87,88] For all patients who have received a hamstring autograft, isolated hamstring strengthening should be included in the return to sport progression, including NWB hamstring curls, unilateral bridges, exercise ball hamstring curls, and Nordic hamstring exercises to normalize any hamstring strength deficits that may be present.

Quadriceps strength symmetry of 80% is recommended before the initiation of running,[71,76] and greater than 90% before returning to sports.[71,89,90] The European Board of Sports Rehabilitation recommends the more stringent criteria of 100% strength symmetry as measured by a battery of tests for returning to competitive, pivoting, or contact sports.[90] Hamstring to quadriceps (H:Q) strength ratios [91] may indicate how effectively the hamstring muscles can counteract anterior tibial translation. A H:Q ratio of at least 85%[49] has been recommended before clearing athletes to return to sport; however, improvements in the H:Q ratio should not be made at the expense of quadriceps strength.

CONCLUSION

Return to pre-injury level of sports participation after ACL reconstruction is often suboptimal and the risk for graft injury or contralateral injury requiring additional surgery is significant. Younger athletes are more likely to return to sport within the first year after reconstruction but there is a greater risk of re-injury and risk of contralateral injury. Resolving impairments while eliminating movement patterns associated with injury and allowing sufficient time for graft healing to occur likely gives the athlete the best chance to return to sport without further incident. At this time, using MRI to investigate graft healing is promising; however, it has not been validated to ensure graft maturity and biomechanical strength. Additional research is needed to identify objective imaging and functional testing criteria to improve clinical decision making for the return to sport phase after ACL reconstruction.

CLINICAL RECOMMENDATIONS WITH SORT GRADES

Grade A. Return to sport rates vary considerably based on patient age, sex, and type of sport. Patient education should reflect this variability.

Grade B. Because re-injury or contralateral injury risk is significant and most likely to occur within the first year after surgery, patients should be encouraged to delay return to sport pending graft healing timeframes and full resolution of impairments, and functional excellence.

Grade B. Quadriceps strength should be explicitly measured and symmetry restored before beginning the return to sport phase in order to limit aberrant movements with sport specific activity.

REFERENCES

1. Lynch AD, Logerstedt DS, Grindem H, et al. Consensus criteria for defining 'successful outcome' after ACL injury and reconstruction: a Delaware-Oslo ACL cohort investigation. *Br J Sports Med*. 2013 Jul 23.
2. Cascio BM, Culp L, Cosgarea AJ. Return to play after anterior cruciate ligament reconstruction. *Clinics in sports medicine*. 2004;23(3):395-408, ix.
3. Marx RG, Jones EC, Angel M, Wickiewicz TL, Warren RF. Beliefs and attitudes of members of the American Academy of Orthopaedic Surgeons regarding the treatment of anterior cruciate ligament injury. *Arthroscopy*. 2003;19(7):762-70.
4. Barber-Westin S. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthosc.* 2011; 27(12): 1697-1705.
5. Feller J, Webster KE. Return to sport following anterior cruciate ligament reconstruction. *International orthopaedics*. 2013;37(2):285-90.
6. Busfield BT, Kharrazi FD, Starkey C, Lombardo SJ, Seegmiller J. Performance outcomes of anterior cruciate ligament reconstruction in the National Basketball Association. *Arthroscopy*. 2009;25(8):825-30.
7. Shah VM, Andrews JR, Fleisig GS, McMichael CS, Lemak LJ. Return to play after anterior cruciate ligament reconstruction in National Football League athletes. *Am J Sports Med*. 2010;38(11):2233-9.
8. Walden M, Hagglund M, Magnusson H, Ekstrand J. Anterior cruciate ligament injury in elite football: a prospective three-cohort study. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(1):11-9.
9. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med*. 2011;45(7):596-606.

10. McCullough KA, Phelps KD, Spindler KP, et al. Return to high school- and college-level football after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Am J Sports Med*. 2012;40(11):2523-9.

11. Marx RG, et al. Development and evaluation of an activity rating scale for disorders of the knee. *Am J Sports Med*. 2001; 29(2): 213-218.

12. Cameron KL, et al. Reference values for the marx activity rating scale in a young athletic population: history of knee ligament injury is associated with higher scores. *Sports Health*. 2015; 7(5): 403-408.

13. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med*. 2011;39(3):538-43.

14. Grindem H, Eitzen I, Moksnes H, Snyder-Mackler L, Risberg MA. A pair-matched comparison of return to pivoting sports at 1 year in anterior cruciate ligament-injured patients after a nonoperative versus an operative treatment course. *Am J Sports Med*. 2012;40(11):2509-16.

15. Brophy RH, Schmitz L, Wright RW, et al. Return to play and future ACL injury risk after ACL reconstruction in soccer athletes from the Multicenter Orthopaedic Outcomes Network (MOON) group. *Am J Sports Med*. 2012;40(11):2517-22.

16. Mascarenhas R, Tranovich MJ, Kropf EJ, Fu FH, Harner CD. Bone-patellar tendon-bone autograft versus hamstring autograft anterior cruciate ligament reconstruction in the young athlete: A retrospective matched analysis with 2-10 year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(8):1520-7.

17. Shelbourne KD, et al. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patella tendon autograft. *Am J Sports Med*. 2009; 37(2): 246-251.

18. Ardern CL, Taylor NF, Feller JA, Webster KE. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2012;40(1):41-8.

19. Vyas D, Rabuck SJ, Harner CD. Allograft anterior cruciate ligament reconstruction: indications, techniques, and outcomes. *J Orthop Sports Phys Ther*. 2012;42(3):196-207.

20. Abe S, Kurosaka M, Iguchi T, Yoshiya S, Hirohata K. Light and electron microscopic study of remodeling and maturation process in autogenous graft for anterior cruciate ligament reconstruction. *Arthroscopy*. 1993;9(4):394-405.

21. Claes S, Verdonk P, Forsyth R, Bellemans J. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *Am J Sports Med*. 2011;39(11):2476-83.

22. Falconiero RP, DiStefano VJ, Cook TM. Revascularization and ligamentization of autogenous anterior cruciate ligament grafts in humans. *Arthroscopy*. 1998;14(2):197-205.

23. Rougraff BT, Shelbourne KD. Early histologic appearance of human patellar tendon autografts used for anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1999;7(1):9-14.

24. Sanchez M, Anitua E, Azofra J, Prado R, Muruzabal F, Andia I. Ligamentization of tendon grafts treated with an endogenous preparation rich in growth factors: gross morphology and histology. *Arthroscopy*. 2010;26(4):470-80.

25. Amiel D, Kleiner JB, Roux RD, Harwood FL, Akeson WH. The phenomenon of "ligamentization": anterior cruciate ligament reconstruction with autogenous patellar tendon. *J Orthop Res*. 1986;4(2):162-72.

26. Fleming BC, Vajapeyam S, Connolly SA, Magarian EM, Murray MM. The use of magnetic resonance imaging to predict ACL graft structural properties. *J Biomech*. 2011;44(16):2843-6.

27. Muramatsu K, Hachiya Y, Izawa H. Serial evaluation of human anterior cruciate ligament grafts by contrast-enhanced magnetic resonance imaging: comparison of allografts and autografts. *Arthroscopy*. 2008;24(9):1038-44.

28. Prodromos C, Joyce B, Shi K. A meta-analysis of stability of autografts compared to allografts after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(7):851-6.

29. Ntoulia A, Papadopoulou F, Ristanis S, Argyropoulou M, Georgoulis AD. Revascularization process of the bone--patellar tendon--bone autograft evaluated by contrast-enhanced magnetic resonance imaging 6 and 12 months after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2011;39(7):1478-86.

30. Weiler A, Peters G, Maurer J, Unterhauser FN, Sudkamp NP. Biomechanical properties and vascularity of an anterior cruciate ligament graft can be predicted by contrast-enhanced magnetic resonance imaging. A two-year study in sheep. *Am J Sports Med*. 2001;29(6):751-61.

31. Biercevicz AM, Miranda DL, Machan JT, Murray MM, Fleming BC. In Situ, noninvasive, T2*-weighted MRI-derived parameters predict ex vivo structural properties of an anterior cruciate ligament

reconstruction or bioenhanced primary repair in a porcine model. *Am J Sports Med*. 2013;41(3):560-6.

32. Biercevicz AM, Murray MM, Walsh EG, Miranda DL, Machan JT, Fleming BC. T2 * MR relaxometry and ligament volume are associated with the structural properties of the healing ACL. *J Orthop Res*. 2014;32(4):492-9.

33. Kato Y, Maeyama A, Lertwanich P, et al. Biomechanical comparison of different graft positions for single-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(4):816-23.

34. Tashman S, Kopf S, Fu FH. The Kinematic Basis of ACL Reconstruction. *Operative techniques in sports medicine*. 2008;16(3):116-8.

35. Siebold R, Dehler C, Ellert T. Prospective randomized comparison of double-bundle versus single-bundle anterior cruciate ligament reconstruction. *Arthroscopy*. 2008;24(2):137-45.

36. Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med*. 2002;30(5):660-6.

37. Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury: A review of the literature-part 2: hormonal, genetic, cognitive function, previous injury, and extrinsic risk factors. *Sports Health*. 2012;4(2):155-61.

38. Lind M, Menhert F, Pedersen AB. Incidence and outcome after revision anterior cruciate ligament reconstruction: results from the Danish registry for knee ligament reconstructions. *Am J Sports Med*. 2012;40(7):1551-7.

39. Wasserstein D, Khoshbin A, Dwyer T, et al. Risk factors for recurrent anterior cruciate ligament reconstruction: a population study in Ontario, Canada, with 5-year follow-up. *Am J Sports Med*. 2013;41(9):2099-107.

40. Wright RW, Magnussen RA, Dunn WR, Spindler KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: a systematic review. *J Bone Joint Surg Am*. 2011;93(12):1159-65.

41. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med*. 2012;22(2):116-21.

42. van Eck CF, Schkrohowsky JG, Working ZM, Irrgang JJ, Fu FH. Prospective analysis of failure rate and predictors of failure after anatomic anterior cruciate ligament reconstruction with allograft. *Am J Sports Med*. 2012;40(4):800-7.

43. Myer GD, Martin L, Jr., Ford KR, et al. No association of time from surgery with functional deficits in athletes after anterior cruciate ligament reconstruction: evidence for objective return-to-sport criteria. *Am J Sports Med*. 2012;40(10):2256-63.

44. Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med*. 2006;34(3):490-8.

45. Paterno MV, et al. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconsttruction. *Clin Journal of Sports Med.* 2007; 17(4): 258-262.

46. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33(4):492-501.

47. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med*. 2010;38(10):1968-78.

48. Smith HC, Johnson RJ, Shultz SJ, et al. A prospective evaluation of the Landing Error Scoring System (LESS) as a screening tool for anterior cruciate ligament injury risk. *Am J Sports Med*. 2012;40(3):521-6.

49. Kiefer AW, Ford KR, Paterno MV, et al. Inter-segmental postural coordination measures differentiate athletes with ACL reconstruction from uninjured athletes. *Gait & posture*. 2013;37(2):149-53.

50. Myer GD, Ford KR, Brent JL, Hewett TE. An integrated approach to change the outcome part II: targeted neuromuscular training techniques to reduce identified ACL injury risk factors. *J Strength Cond Res*. 2012;26(8):2272-92.

51. Delahunt E, Sweeney L, Chawke M, et al. Lower limb kinematic alterations during drop vertical jumps in female athletes who have undergone anterior cruciate ligament reconstruction. *J Orthop Res*. 2012;30(1):72-8.

52. Deneweth JM, Bey MJ, McLean SG, Lock TR, Kolowich PA, Tashman S. Tibiofemoral joint kinematics of the anterior cruciate ligament-reconstructed knee during a single-legged hop landing. *Am J Sports Med*. 2010;38(9):1820-8.

53. Gokeler A, Hof AL, Arnold MP, Dijkstra PU, Postema K, Otten E. Abnormal landing strategies after ACL reconstruction. *Scan J Med Sci Sport*. 2010;20(1):e12-9.

54. Stearns KM, Pollard CD. Abnormal frontal plane knee mechanics during sidestep cutting in female soccer athletes after anterior cruciate ligament

reconstruction and return to sport. *Am J Sports Med*. 2013;41(4):918-23.

55. Nagai T, Heebner NR, Sell TC, Nakagawa T, Fu FH, Lephart SM. Restoration of sagittal and transverse plane proprioception following anatomic double-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(9):2048-56.
56. White K, Di Stasi SL, Smith AH, Snyder-Mackler L. Anterior cruciate ligament- specialized post-operative return-to-sports (ACL-SPORTS) training: a randomized control trial. *BMC musculoskeletal disorders*. 2013;14:108.
57. Mizner RL, Kawaguchi JK, Chmielewski TL. Muscle strength in the lower extremity does not predict postinstruction improvements in the landing patterns of female athletes. *J Orthop Sports Phys Ther*. 2008;38(6):353-61.
58. Myer GD, Ford KR, Hewett TE. The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *J Electromyogr Kinesiol*. 2005;15(2):181-9.
59. Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. *J Orthop Sports Phys Ther*. 2011;41(9):625-32.
60. Arendt EA. Anterior cruciate ligament injuries. *Curr Womens Health Rep*. 2001; 1(3): 211-217.
61. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer NCAA data and review of literature. *Am J Sports Med*. 1995;23(6):694-701.
62. Salci Y, Kentel BB, Heycan C, Akin S, Korkusuz F. Comparison of landing maneuvers between male and female college volleyball players. *Clinical Biomech* (Bristol, Avon). 2004;19(6):622-8.
63. Decker MJ, Torry MR, Wyland DJ, Sterett WI, Richard Steadman J. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomech* (Bristol, Avon). 2003;18(7):662-9.
64. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy*. 2012;28(4):526-31.
65. Joseph AM, et al. A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. *J Athl Train*. 2013; 48(6): 810-817.
66. Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury: a review of the literature - part 1: neuromuscular and anatomic risk. *Sports Health*. 2012;4(1):69-78.
67. Sturgill LP, Snyder-Mackler L, Manal TJ, Axe MJ. Interrater reliability of a clinical scale to assess knee joint effusion. *J Orthop Sports Phys Ther*. 2009;39(12):845-9.
68. Hopkins JT. Knee joint effusion and cryotherapy alter lower chain kinetics and muscle activity. *J Ath Train*. 2006;41(2):177-84.
69. Hopkins JT, Ingersoll CD, Krause BA, Edwards JE, Cordova ML. Effect of knee joint effusion on quadriceps and soleus motoneuron pool excitability. *Med Sci Sport Ex*. 2001;33(1):123-6.
70. Lynch AD, Logerstedt DS, Axe MJ, Snyder-Mackler L. Quadriceps activation failure after anterior cruciate ligament rupture is not mediated by knee joint effusion. *J Orthop Sports Phys Ther*. 2012;42(6):502-10.
71. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: a criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42(7):601-14.
72. Wilk KE, Reinold MM, Hooks TR. Recent advances in the rehabilitation of isolated and combined anterior cruciate ligament injuries. *Orthop Clin N Am*. 2003;34(1):107-37.
73. Hart JM, Pietrosimone B, Hertel J, Ingersoll CD. Quadriceps activation following knee injuries: a systematic review. *J Athl Train*. 2012;45(1):87-97.
74. Palmieri-Smith RM, Thomas AC, Wojtys EM. Maximizing quadriceps strength after ACL reconstruction. *Clin Sports Med*. 2008;27(3):405-24, vii-ix.
75. Schmitt LC, Paterno MV, Hewett TE. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2012;42(9):750-9.
76. Lewek M, Rudolph K, Axe M, Snyder-Mackler L. The effect of insufficient quadriceps strength on gait after anterior cruciate ligament reconstruction. *Clinical Biomech* (Bristol, Avon). 2002;17(1):56-63.
77. Augustsson J. Documentation of strength training for research purposes after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(8):1849-55.
78. Kvist J. Rehabilitation following anterior cruciate ligament injury: current recommendations for sports participation. *Sports Med*. 2004;34(4):269-80.
79. Escamilla RF, Macleod TD, Wilk KE, Paulos L, Andrews JR. Anterior cruciate ligament strain and tensile forces for weight-bearing and non-weight-bearing exercises: a guide to exercise selection. *J Orthop Sports Phys Ther*. 2012;42(3):208-20.

80. Beynnon BD, Fleming BC. Anterior cruciate ligament strain in-vivo: a review of previous work. *J Biomech*. 1998;31(6):519-25.

81. Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligamentization after cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(9):834-42.

82. West RV, Harner CD. Graft selection in anterior cruciate ligament reconstruction. *J Am Acad Ortho Surg*. 2005;13(3):197-207.

83. Kim KM, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *J Orthop Sports Phys Ther*. 2010;40(7):383-91.

84. Fitzgerald GK, Piva SR, Irrgang JJ. A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2003;33(9):492-501.

85. Snyder-Mackler L, Delitto A, Bailey SL, Stralka SW. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomized clinical trial of electrical stimulation. *J B J S*. 1995;77(8):1166-73.

86. Keays SL, Bullock-Saxton JE, Newcombe P, Keays AC. The relationship between knee strength and functional stability before and after anterior cruciate ligament reconstruction. *J Orthop Res*. 2003;21(2):231-7.

87. Ardern CL, Webster KE. Knee flexor strength recovery following hamstring tendon harvest for anterior cruciate ligament reconstruction: a systematic review. *Orthop Rev* (Pavia). 2009;1(2).

88. Nakamura N, Horibe S, Sasaki S, et al. Evaluation of active knee flexion and hamstring strength after anterior cruciate ligament reconstruction using hamstring tendons. *Arthroscopy*. 2002;18(6):598-602.

89. Hartigan EH, Axe MJ, Snyder-Mackler L. Time line for noncopers to pass return-to-sports criteria after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2012;40(3):141-54.

90. Thomee R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(11):1798-805.

91. Aagaard P, Simonsen EB, Magnusson SP, Larsson B, Dyhre-Poulsen P. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *Am J Sports Med*. 1998;26(2):231-7.

APPENDIX 1: UPMC CENTER FOR SPORTS MEDICINE POST-OP ACL PROTOCOL, CURRENTLY BEING RESEARCHED.

ACL Reconstruction Functional Rehabilitation Protocol

Formal physical therapy and sport specific training will last **8-12 months**. All patients will be issued a neuromuscular electric stimulation unit (NMES) for home use with guidelines. A continuous passive motion (CPM) device will be issued at the physician's discretion.

<u>Activities of Daily Living Guidelines Following Surgery</u>
Patients may begin the following activities at the timeframes indicated (unless otherwise specified by the physician):

- No bathing or submerging the wound in water until the sutures have been removed, the scabs have fallen off, and the skin is completely closed
- Showering is allowed after the surgical dressing is removed; a waterproof dressing is not needed as the incision can get wet. A shower seat is advised to avoid falls
- The brace will be locked in extension for gait and sleep for the first week
- Use of crutches and brace for ambulation for 4-6 weeks. Must be cleared by physician and/or physical therapist to begin walking without assistive devices
- Weight-bearing as tolerated immediately after surgery unless otherwise instructed
- For R knee surgery, no driving for 4-6 weeks. As long as they are in the brace, patients are medically liable if in an accident. For L knee surgery, patients may drive after one week as long as they have an automatic and have stopped taking narcotics.
  - Must pass driving test for R knee: While sitting, complete eight fast foot taps over shoe then stand up

<u>Brace and Crutch Use Guidelines</u>
Patients will be WBAT after surgery. The post-op brace is locked in extension initially for the first week with the exception that it may be unlocked for post-op exercises and CPM use. It is unlocked for walking once the patient reaches full knee hyperextension, usually 1 week post-op.

BRACE IS DISCONTINUED WHEN:
- The patient is at least 4-6 weeks post-op
- The patient has full and equal passive and active knee hyperextension and >100° flexion
  - Active knee extension is measured via straight leg raise
- The patient demonstrates normal pain-free walking without an increase in swelling

CRUTCHES ARE DISCONTINUED WHEN:
- The patient will initially be WBAT with bilateral crutches for 4 weeks; they will then transition to one crutch before walking without the crutches over the next 2 weeks

- The patient has full and equal passive and active knee hyperextension and >100° flexion
- The patient is able to walk and maintain the knee in full extension without use of assistive device (i.e. does not walk with "bent knee" gait pattern)
- The patient has no increased knee pain or swelling with independent weightbearing

Special weightbearing guidelines for concomitant procedures
- The brace will be worn at least 6 weeks for combined ACL/MCL procedures, concomitant meniscal repairs, and microfracture procedures
- MENISCUS REPAIR: Patients that also undergo a meniscus repair procedure will be NWB for 4 weeks, 50% WB for 2 weeks, then WBAT after 6 weeks
- MICROFRACTURE or ARTICULAR CARTILAGE PROCEDURE: Patients that also undergo a microfracture or articular cartilage procedure will be NWB for 4 weeks, 50% WB for 2 weeks, then WBAT after 6 weeks

Estimated Return to Sport Milestones (based on graft healing time and passing functional testing):

	Jogging	Low-level Agility	Jumping	Cutting	Return to Sport
Bone-Patellar Tendon-Bone Autograft	4-5 months	5-6 months	6-7 months	7-8 months	9+ months
Hamstring/ Quad Tendon Autograft	4-5 months	5-6 months	6-7 months	7-8 months	9+ months
Bone-Patellar Tendon-Bone Allograft	5-6 months	6-7 months	7-8 months	8-9 months	10+ months
Soft Tissue Allograft	5-6 months	6-7 months	7-8 months	8-9 months	10-12+ months

These times are estimated based on graft healing and are dependent upon the patient passing functional testing in physical therapy that assesses strength and neuromuscular control. These times may be longer if the patient also had a concomitant procedure such as a meniscal repair, microfracture/articular cartilage procedure or other ligament injury or procedure. They physician may also order an MRI to assess graft healing to assist in making return to sports activity decisions.

Phase 1: Initial Post-Op Care

Goals for Phase 1 include restoration of ROM and mobility, management of pain and edema, and initiation of strengthening with emphasis on the quadriceps. The post-operative brace may be removed for treatment. Closed kinetic chain (CKC) exercises should be performed in the protected range of 0-45° of flexion and open kinetic chain (OKC) knee extension exercises should stay in the protected range of 90-60° of flexion. Exercises should include but are not limited to:

Weeks 1-4:
- 4-way patellar mobilization
- High intensity neuromuscular electrical stimulation
- Exercises to regain hyperextension – hamstring and gastrocnemius stretching, prone hang, manual overpressure, seated heel props with bag hang and/or with cuff weights
- Exercises to regain full flexion – heelslides, posterior tibial mobilizations
  - NOTE: Flexion is limited to 90° for 4 weeks with concomitant meniscus repairs
- Early strengthening – quad sets in full knee hyperextension, 4-way straight leg raises, terminal knee extension (CKC), mini-squats, isometric quadriceps setting at 90° and 60° of knee flexion
- Balance and proprioception exercises – progressing from weight shifting during bilateral stance progressing to unilateral stance exercises on stable and unstable surfaces, with eyes open and eyes closed
- Gait training – weight-shifts (side to side and forward/backward)
- Progress strengthening to include – leg press (single leg), OKC knee extension from 90-60° with ankle cuff weights, step-ups, step-downs, bridges, hamstring curls, wall slides
- *NOTE: No OKC hamstring curls with concomitant meniscal repair or hamstring autograft for first 6 weeks*

Goals at 2 weeks post-op include:
- Passive and active hyperextension (as measured when doing a straight leg raise) should be equal to the uninvolved side and flexion >100°
- Reduced pain and swelling (rated 2+ or less via Stroke Test)
- If SLR doesn't reach neutral extension (0°) by 2 weeks post-op, increase frequency of PT and notify the physician

Goals at 4 weeks post-op include:
- Full flexion (unless ROM restriction from concomitant meniscus repair)
- No active inflammation (i.e. no increased pain, swelling or warmth) as a result of exercise. Swelling should be rated 1+ or less via Stroke Test
- Preparation for full weightbearing and independent gait

The patient's visit frequency will be set by the PT for 1-3 times per week. If the patient is not meeting the range of motion milestones or if they are having difficulty with regaining quadriceps control/have a knee extensor lag, the MD should be notified and visit frequency should increase.

Weeks 4-16:
- Stretching exercises and manual therapy if flexion or extension is still limited
- Cardio – bike, elliptical
- Gait training on treadmill progressing to fast treadmill walking
- Aquatic therapy (if available) – 4-way straight leg raises, squats, bicycle kicking, fast walking progressing to a jog
- Progress strengthening to include – OKC knee extension (90-60° for the first 10 weeks, 90-45° for weeks 10-16), single leg squats, lunges, mini-band walking, deadlifts, step and holds (Individual steps from the uninjured limb onto the injured limb, at least the distance of the individual's normal stride length. The individual is cued to imagine they are stepping over a puddle of water and to land with a heel-toe gait pattern to simulate walking and progressing the distance to prepare for running without excessive stiffening or excessive knee flexion)
- Perturbation training

PT should focus on aggressive strengthening, particularly of the quadriceps. Visit frequency may be reduced if the patient has regular access to weight training equipment at a gym.

Weeks 16-20:

- CKC exercises should be progressed to ~60-75° of knee flexion provided that this does not cause any patellofemoral pain.
- OKC exercises should be progressed to full range 90-0° provided that this does not cause any patellofemoral pain.
- Prepare to pass screening exam to begin running

Goal at 4-6 months post-op (depending on graft type): PASS SCREENING TEST TO BEGIN RUNNING

- No abnormal gait patterns while walking as fast as they can on the treadmill for 15 minutes
- 30 step and holds without loss of balance or excessive motion outside of the sagittal plane
- 10 consecutive single leg squats to 45° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot
- ≥ 80% 1-repetition maximum (1-RM) on the leg press (90-0°)
- ≥ 80% 1-repetition maximum (1-RM) on the knee extension machine (90-45°)
- ≥ 90% composite score on Y-balance test. Composite score = (anterior reach + posteromedial reach + posterolateral reach)/(3 x limb length)

<u>Phase 2: Running</u>

Begin jogging on a treadmill or a track when the patient passes the screening exam AND is cleared by the physician. Running should begin at slow, comfortable speeds for short durations and distances. The patient may progress in speed, time and distance as long as there is no development or increase in pain, swelling, warmth, or gait deviations. See Running Progression Guidelines handout.

The patient should be seen by the physical therapist <u>once every 2-3 weeks</u> while running tolerance and endurance progresses. Aggressive strengthening should continue in preparation to pass the screening test to begin agility drills.

Patients who undergo a Quadriceps tendon autograft with bone plug will need an x-ray at their 6 month post-op visit in order to be cleared for Biodex testing to ensure healing of the harvest site.

Goals at 5-7 months post-op: PASS SCREENING TEST TO BEGIN LOW-LEVEL AGILITY DRILLS

- ≥ 85% 1-RM on the leg press (90-0°)
- ≥ 85% 1-RM on the knee extension machine (90-0°) or Biodex testing if available
- 10 consecutive single leg squats >45° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 75% extra weight compared to the other side (dumbbells, weight vest, etc.) Body weight is not part of the equation
- 100% composite score on Y-balance test. Composite score = (anterior reach + posteromedial reach + posterolateral reach)/(3 x limb length)
- Be able to run 2 miles continuously without pain, swelling, warmth, or gait deviations

<u>Phase 3: Agility Training</u>

When the patient passes the screening exam AND is cleared by the physician, they may begin agility drills that include lateral shuffling, forward/backward shuttle runs, carioca, and ladder drills.

Physical therapy should focus on elimination of compensation patterns, particularly when the patient decelerates. Aggressive strengthening should continue in preparation to pass the screening test to begin jumping.

If the patient is not planning to return to sports participation, they may be discharged from PT once they are able to do agility training at sub-max speeds without new inflammation.

Goals at 6-8 months post-op: PASS SCREENING TEST TO BEGIN JUMPING

- ≥ 90% 1-RM on the leg press (90-0°)
- ≥ 90% 1-RM on the knee extension machine (90-0°) or Biodex testing if available
- 10 consecutive single leg squats to 60° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 85% extra weight compared to the other side (dumbbells, weight vest, etc.). Body weight is not part of the equation
- No compensation patterns with deceleration during agility drills performed at near 100% effort

<u>Phase 4: Jumping (Two Feet)</u>

When the patient passes the screening exam AND is cleared by the physician, begin jumping. Jumping is with two feet, both taking off and landing.

Jumps should start with single vertical jumps and the physical therapist should watch for medial collapse of the knees both when loading into the jump and landing from the jump. When the patient demonstrates consistent equal weightbearing when landing, progress with forward, side to side, rotating, and box jumps. As the patient demonstrates consistent good form, progress from single jumps to consecutive jumps.

Physical therapy should focus on teaching the patient soft, athletic landings and avoidance of compensation strategies. Aggressive strengthening should continue in preparation to pass the screening test to begin hopping and cutting.

Goals at 7-9 months post-op: PASS SCREENING TEST TO BEGIN CUTTING AND HOPPING

- 10 consecutive single leg squats to 60° without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 90% extra weight compared to the other side (dumbbells, weight vest, etc.). Body weight is not part of the equation

- No display of medial collapse of the knees when loading into or landing from jumps, and equal weight distribution when initiating and landing the jumps

Phase 5: Hopping (Single Leg) and Cutting

When the patient passes the screening exam AND is cleared by the physician, they may begin hopping and cutting. Hopping is with 1 foot, both taking off and landing. Hopping should follow the same progression as jumping.

Patients should first practice running in an "S" pattern, then progress to 45° cuts, and then to sharper angles. Pivoting and cut and spinning should begin when the patient is competent with cutting at sharp angles. Patients should be able to tolerate cutting, pivoting and cut and spinning at full speed before practicing unanticipated cutting. The patient should not progress their speed if they demonstrate any excessive knee medial deviation or express a lack of confidence when cutting.

Sprinting should begin with transitions from running directly into sprinting short distances. Distance should be progressed to sprinting a 40 yard dash, then a 100 yard dash, and finally sprints to fatigue.

Physical therapy should focus on improving the form and speed of hopping and cutting. Aggressive strengthening should continue in preparation to return to sports participation.

Goals at 9-12 months: PREPARE TO TAKE RETURN TO SPORTS TEST

- Display a normal running pattern that does not increase pain, swelling, or warmth
- Practice and display no hesitation or compensation strategies during agility drills (particularly when decelerating) when performed at 100% effort
- Practice and display normal loading (no medial knee collapse) and soft, athletic landings from all jumps and hops
- Practice and display no hesitation or compensation strategies during cutting drills (particularly when decelerating) when performed at perceived 100% effort

Returning to Sports Participation

The patient should be able to perform all agility, plyometric, and cutting exercises at full speed without compensation patterns or complaints of pain, swelling, or warmth. Exercises should include anticipated and unanticipated cutting and jumping.

Physical therapy should be geared on sport specific training as per the patient's sport and position.

The patient may return to sports participation when they pass the ACL Return to Sports Test AND receive clearance by the physician.

Post-Op ACL Reconstruction Return to Sport Test

Name:_________________________________ Date:___________

1. Single broad jump, landing on one foot - *Involved/Uninvolved Distance* = _______/_______ = _____
2. Triple broad jump, landing last jump on one foot – *Involved/Uninvolved Distance* = _______/_______ = _____
3. Single leg forward hop - *Involved/Uninvolved Distance* = _______/_______ = _____
4. Single leg triple hop - *Involved/Uninvolved Distance* = _______/_______ = _____
5. Single leg triple crossover hop - *Involved/Uninvolved Distance* = _______/_______ = _____
6. Timed 6-meter single leg hop - *Uninvolved/Involved Time* = _______/_______ = _____
7. Single leg lateral hop - *Involved/Uninvolved Distance* = _______/_______ = _____
8. Single leg medial hop - *Involved/Uninvolved Distance* = _______/_______ = _____
9. Single leg medial rotating hop - *Involved/Uninvolved Distance* = _______/_______ = _____
10. Single leg lateral rotating hop - *Involved/Uninvolved Distance* = _______/_______ = _____
11. Single leg vertical hop - *Involved/Uninvolved Height* = _______/_______ = _____
12. 10 yard Lower Extremity Functional Test
    - Sprint/back-peddle, Shuffle, Carioca, Sprint
    - Must perform at perceived full speed and not display hesitation or compensation strategies when decelerating
    - Recommended goal for males: 18-22 seconds; females: 20-24 seconds
13. 10 yard Pro-agility Run
    - Both directions
    - Must perform at perceived full speed and not display hesitation or compensation strategies when decelerating
    - Recommended goal for males: 4.5-6.0 seconds; females: 5.2-6.5 seconds

Criteria to Return to Practice:

1. MD clearance
2. Pass Return to Sport Test with ≥90% results for each test.

Criteria to Return to Competition:

1. MD clearance
2. Tolerate full practice sessions with opposition and contact (if applicable) performed at 100% effort without any increased pain, increased effusion, warmth, or episodes of giving way.